Networking & Information Technology Research and Development Program

High End Computing Interagency Working Group (HEC IWG)

&

Big Data Senior Steering Group (BDSSG)

Supercomputing and Big Data: From Collision to Convergence



High Performance Data Analytics: Real-world challenges

All involve analyzing massive streaming complex networks:

Health care

 disease spread, detection and prevention of epidemics/pandemics (e.g. SARS, Avian flu, H1N1 "swine" flu)

Massive social networks

 understanding communities, intentions, population dynamics, pandemic spread, transportation and evacuation

Intelligence

 business analytics, anomaly detection, security, knowledge discovery from massive data sets

Systems Biology

• understanding complex life systems, drug design, microbial research, understand life, unravel mysteries of disease

Electric Power Grid

• communication, transportation, energy, water, food supply

Modeling and Simulation

• Perform full-scale economic-social-political simulations

Unlike traditional applications in computational science and engineering, solving these problems at scale often raises new research challenges because of

- sparsity and the lack of locality in the massive data,
- design of parallel algorithms for massive, streaming data analytics, and
- the need for new HPDA supercomputers that are energy-efficient, resilient, and easy-to-program.

REQUIRES PREDICTING / INFLUENCE CHANGE IN REAL-TIME AT SCALE



Recommendations

- High Performance Data Analytics will require new
 - High-performance computing platforms
 - Streaming algorithms
 - Energy-efficient implementations

and are promising to solve real-world challenges!

 Mapping applications to high performance architectures may yield 6 or more orders of magnitude performance improvement



3

Backup Slides



David A. Bader

Dr. David A. Bader

- Full Professor, Computational Science and Engineering
- Executive Director for High Performance Computing.
- IEEE Fellow, AAAS Fellow
- interests are at the intersection of high-performance computing and realworld applications, including computational biology and genomics and massive-scale data analytics.
- Over \$165M of research awards
- Steering Committees of the major HPC conferences, IPDPS and HiPC
- Multiple editorial boards in parallel and high performance computing
 - EIC of IEEE Transactions on Parallel and Distributed Systems
- Elected chair of IEEE and SIAM committees on HPC
- **◆** 230+ publications, ≥ 4,790 citations, *h*-index ≥ 38
- National Science Foundation CAREER Award recipient
- Directed the Sony-Toshiba-IBM Center for the Cell/B.E. Processor
- Founder of the Graph500 List for benchmarking "Big Data" computing platforms
- Recognized as a "RockStar" of High Performance Computing by InsideHPC in 2012 and as HPCwire's People to Watch in 2012 and 2014.







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- Solves real-world problems and creates future leaders
- Enables breakthroughs in scientific discovery and engineering practice
- Uses the most advanced resources, techniques and ideas
- Is highly collaborative with an impressive roster of GT and industry partners

Ten Years of Success





Founded: 2005

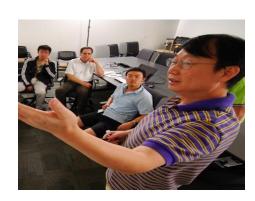
Chair: David Bader



- Faculty:
 - 11 tenure track (FY 16)
 - 4 joint appointments
 - 6 adjunct faculty
 - 5 research scientists
- Administrative staff: 5
- Research expenditures: \$5.6 million (FY 2015)
- High impact: \$463K expenditure per faculty member

Award-Winning Faculty

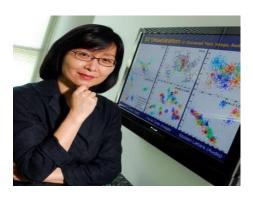
Georgia School of Computational Tech Science and Engineering



- 11 tenure-track faculty members (FY 16)
- 1 Regents' professor

Yahoo! Labs

- 5 NSF CAREER awards
- 2 IEEE fellows, 2 AAAS fellows, and 1 SIAM fellow
- 3 recent best paper awards and 2 finalists from SIAM, IEEE, etc.



Several recent awards from industry:

Accenture	Raytheon
IBM	LexisNexis
Google	Microsoft Research
NVIDIA	Sony
Intel	Cray
Lockheed Martin	Exxon Mobil

Faculty: Interdisciplinary Innovators





Professor













Georgia





Chemistry







12 Pinnacle Projects > US\$1M





S. Aluru (PI), W. Feng, K. Olukotun, P. Schnable, C. Sing, and J. Zola, "BIGDATA: Mid-Scale: DA: Collaborative Research: Genomes Galore - Core Techniques, Libraries, and Domain Specific Languages for High-Throughput DNA Sequencing," NSF/NIH Bigdata Initiative, **\$2M**

A. Somani, **S. Aluru** (Co-PI), R. Fox, E. Takle, and M. Gordon, "MRI: Acquisition of a HPC system for Data-Driven Discovery in Science and Engineering," National Science Foundation, **\$1.8M**

S. Aluru (PI), K. Dorman, and P.S. Schnable, "AF:Medium: Parallel Algorithms and Software for High-throughput Sequence Assembly," National Science Foundation, **\$1M**

Polo Chau (Co-PI), "Center of Excellence for Mobile Sensor Data-to-Knowledge (MD2K)," National Institute of Health, \$1.25M

R. Fujimoto (Co-PI) and J. Crittenden (PI), "Participatory Modeling of Complex Urban Infrastructure Systems," National Science Foundation, \$2.5M

R. Fujimoto (PI), T. Blum, **S. Kalidindi**, W. Newstetter, and **H. Zha**, "Computation-Enabled Design and Manufacturing of High Performance Materials," National Science Foundation, **\$2.8M**

H. Park (PI), H. Zha (Co-PI), B. Drake (Co-PI), J. Choo (Co-PI), and J. Poulson (Co-PI), "Fast Algorithms on Imperfect, Heterogeneous, Distributed Data for Interactive Analysis," DARPA, \$2.7M

H. Park (PI), J. Stasko (Co-PI), A. Gray (Co-PI), J. Monteiro (Co-PI), V. Koltchinskii (Co-PI), "FODAVA-lead: Dimension Reduction and Data Reduction: Foundations for Visualization," National Science Foundation and Department of Homeland Security, **\$3.5M**

D. Bader (PI), **E.J. Riedy** (Co-PI), **R. Vuduc** (Co-PI), and V. Prasanna (PI), "SI2-SSI: Collaborative: The XScala Project: A Community Repository for Model-Driven Design and Tuning of Data-Intensive Applications for Extreme-Scale Accelerator-Based Systems." National Science Foundation, **\$1.2M**

D. Bader (PI), **E.J. Riedy** (Co-PI), "GRATEFUL: GRaph Analysis Tackling power Efficiency, Uncertainty, and Locality, Power Efficiency Revolution for Embedded Computing Technologies (PERFECT) Program," DARPA, **\$2.9M**

J. Sun, Smart Connect Health Project Award, National Science Foundation, \$2.1M

H. Zha (Co-PI), "TWC SBE: TTP Option: Medium: Collaborative: EPICA: Empowering People to Overcome Information Controls and Attacks," National Science Foundation, **\$1.1M** ...and more good news pending...

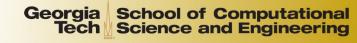
Big Data Analytics

Georgia School of Computational Tech Science and Engineering

Answering the need for algorithms that scale to massive, complex data sets



Core Research Areas









Devise computing solutions at the absolute limits of scale and speed using efficient, reliable and fast algorithms, software, tools and applications

Construct and study algorithms that build models, and make efficient datadriven predictions or decisions

Develop new methods to analyze large and complex data sets, transforming data into value and solve grand challenges

Design fast theoretic algorithms on large-scale graphs, and detect malicious activity

Present data in ways that best yield insight and support decisions as problems scale and complexity increase





Graduate Education



- Ph.D. and MS in Computational Science and Engineering
- Ph.D. and MS in Bioengineering, Ph.D. in Bioinformatics, MS in Analytics





Strength in Diversity: CSE Home Units

School of Aerospace Engineering

School of Biology

Coulter Department of Biomedical Engineering

School of Chemistry and Biochemistry

School of Civil and Environmental Engineering

School of Computational Science and Engineering

School of Industrial and Systems Engineering

School of Mathematics

Students select a **Home** – unit & (*if applicable*) advisor Coursework – **Core** + **Computation** + **Application** Research – **Dissertation** (*MS thesis option* + *PhD only*)

Georgia School of Computational Tech Science and Engineering



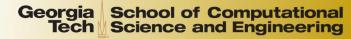
2005 - 2015

Bader, Related Recent Publications (2005-2009)

Georgia School of Computational Tech Science and Engineering

- D.A. Bader, G. Cong, and J. Feo, "On the Architectural Requirements for Efficient Execution of Graph Algorithms," The 34th International Conference on Parallel Processing (ICPP 2005), pp. 547-556, Georg Sverdrups House, University of Oslo, Norway, June 14-17, 2005.
- D.A. Bader and K. Madduri, "Design and Implementation of the HPCS Graph Analysis Benchmark on Symmetric Multiprocessors," The 12th International Conference on High Performance Computing (HiPC 2005), D.A. Bader et al., (eds.), Springer-Verlag LNCS 3769, 465-476, Goa, India, December 2005.
- D.A. Bader and K. Madduri, "Designing Multithreaded Algorithms for Breadth-First Search and st-connectivity on the Cray MTA-2," The 35th International Conference on Parallel Processing (ICPP 2006), Columbus, OH, August 14-18, 2006.
- D.A. Bader and K. Madduri, "Parallel Algorithms for Evaluating Centrality Indices in Real-world Networks," The 35th International Conference on Parallel Processing (ICPP 2006), Columbus, OH, August 14-18, 2006.
- K. Madduri, D.A. Bader, J.W. Berry, and J.R. Crobak, "Parallel Shortest Path Algorithms for Solving Large-Scale Instances," 9th DIMACS Implementation Challenge -- The Shortest Path Problem, DIMACS Center, Rutgers University, Piscataway, NJ, November 13-14, 2006.
- K. Madduri, D.A. Bader, J.W. Berry, and J.R. Crobak, "An Experimental Study of A Parallel Shortest Path Algorithm for Solving Large-Scale Graph Instances," Workshop on Algorithm Engineering and Experiments (ALENEX), New Orleans, LA, January 6, 2007.
- J.R. Crobak, J.W. Berry, K. Madduri, and D.A. Bader, "Advanced Shortest Path Algorithms on a Massively-Multithreaded Architecture," First Workshop on Multithreaded Architectures and Applications (MTAAP), Long Beach, CA, March 30, 2007.
- D.A. Bader and K. Madduri, "High-Performance Combinatorial Techniques for Analyzing Massive Dynamic Interaction Networks," DIMACS Workshop on Computational Methods for Dynamic Interaction Networks, DIMACS Center, Rutgers University, Piscataway, NJ, September 24-25, 2007.
- D.A. Bader, S. Kintali, K. Madduri, and M. Mihail, "Approximating Betewenness Centrality," The 5th Workshop on Algorithms and Models for the Web-Graph (WAW2007), San Diego, CA, December 11-12, 2007.
- David A. Bader, Kamesh Madduri, Guojing Cong, and John Feo, "Design of Multithreaded Algorithms for Combinatorial Problems," in S. Rajasekaran and J. Reif, editors, Handbook of Parallel Computing: Models, Algorithms, and Applications, CRC Press, Chapter 31, 2007.
- Kamesh Madduri, David A. Bader, Jonathan W. Berry, Joseph R. Crobak, and Bruce A. Hendrickson, "Multithreaded Algorithms for Processing Massive Graphs," in D.A. Bader, editor, *Petascale Computing: Algorithms and Applications*, Chapman & Hall / CRC Press, Chapter 12, 2007.
- D.A. Bader and K. Madduri, "SNAP, Small-world Network Analysis and Partitioning: an open-source parallel graph framework for the exploration of large-scale networks," 22nd IEEE International Parallel and Distributed Processing Symposium (IPDPS), Miami, FL, April 14-18, 2008.
- S. Kang, D.A. Bader, "An Efficient Transactional Memory Algorithm for Computing Minimum Spanning Forest of Sparse Graphs," 14th ACM SIGPLAN Symposium on Principles and Practice of Parallel Programming (PPoPP), Raleigh, NC, February 2009.
- Karl Jiang, David Ediger, and David A. Bader. "Generalizing k-Betweenness Centrality Using Short Paths and a Parallel Multithreaded Implementation." The 38th International Conference on Parallel Processing (ICPP), Vienna, Austria, September 2009.
- Kamesh Madduri, David Ediger, Karl Jiang, David A. Bader, Daniel Chavarría-Miranda. "A Faster Parallel Algorithm and Efficient Multithreaded Implementations for Evaluating Betweenness Centrality on Massive Datasets." 3rd Workshop on Multithreaded Architectures and Applications (MTAAP), Rome, Italy, May 2009.
- David A. Bader, et al. "STINGER: Spatio-Temporal Interaction Networks and Graphs (STING) Extensible Representation." 2009.

Bader, Related Recent Publications (2010-2011)



- David Ediger, Karl Jiang, E. Jason Riedy, and David A. Bader. "Massive Streaming Data Analytics: A Case Study with Clustering Coefficients," Fourth Workshop in Multithreaded Architectures and Applications (MTAAP), Atlanta, GA, April 2010.
- Seunghwa Kang, David A. Bader. "Large Scale Complex Network Analysis using the Hybrid Combination of a MapReduce cluster and a Highly Multithreaded System:," Fourth Workshop in Multithreaded Architectures and Applications (MTAAP), Atlanta, GA, April 2010.
- David Ediger, Karl Jiang, Jason Riedy, David A. Bader, Courtney Corley, Rob Farber and William N. Reynolds. "Massive Social Network Analysis: Mining Twitter for Social Good," The 39th International Conference on Parallel Processing (ICPP 2010), San Diego, CA, September 2010.
- Virat Agarwal, Fabrizio Petrini, Davide Pasetto and David A. Bader. "Scalable Graph Exploration on Multicore Processors," The 22nd IEEE and ACM Supercomputing Conference (SC10), New Orleans, LA, November 2010.
- Z. Du, Z. Yin, W. Liu, and D.A. Bader, "On Accelerating Iterative Algorithms with CUDA: A Case Study on Conditional Random Fields Training Algorithm for Biological Sequence Alignment," IEEE International Conference on Bioinformatics & Biomedicine, Workshop on Data-Mining of Next Generation Sequencing Data (NGS2010), Hong Kong, December 20, 2010.
- D. Ediger, J. Riedy, H. Meyerhenke, and D.A. Bader, "Tracking Structure of Streaming Social Networks," 5th Workshop on Multithreaded Architectures and Applications (MTAAP), Anchorage, AK, May 20, 2011.
- D. Mizell, D.A. Bader, E.L. Goodman, and D.J. Haglin, "Semantic Databases and Supercomputers," 2011 Semantic Technology Conference (SemTech), San Francisco, CA, June 5-9, 2011.
- P. Pande and D.A. Bader, "Computing Betweenness Centrality for Small World Networks on a GPU," The 15th Annual High Performance Embedded Computing Workshop (HPEC), Lexington, MA, September 21-22, 2011.
- David A. Bader, Christine Heitsch, and Kamesh Madduri, "Large-Scale Network Analysis," in J. Kepner and J. Gilbert, editor, *Graph Algorithms in the Language of Linear Algebra*, SIAM Press, Chapter 12, pages 253-285, 2011.
- Jeremy Kepner, David A. Bader, Robert Bond, Nadya Bliss, Christos Faloutsos, Bruce Hendrickson, John Gilbert, and Eric Robinson, "Fundamental Questions in the Analysis of Large Graphs," in J. Kepner and J. Gilbert, editor, Graph Algorithms in the Language of Linear Algebra, SIAM Press, Chapter 16, pages 353-357, 2011.

Bader, Related Recent Publications (2012)



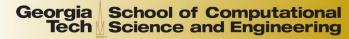
- E.J. Riedy, H. Meyerhenke, D. Ediger, and D.A. Bader, "Parallel Community Detection for Massive Graphs," The 9th International Conference on Parallel Processing and Applied Mathematics (PPAM 2011), Torun, Poland, September 11-14, 2011. Lecture Notes in Computer Science, 7203:286-296, 2012.
- E.J. Riedy, D. Ediger, D.A. Bader, and H. Meyerhenke, "Parallel Community Detection for Massive Graphs," 10th DIMACS Implementation Challenge -- Graph Partitioning and Graph Clustering, Atlanta, GA, February 13-14, 2012.
- E.J. Riedy, H. Meyerhenke, D.A. Bader, D. Ediger, and T. Mattson, "Analysis of Streaming Social Networks and Graphs on Multicore Architectures," The 37th IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), Kyoto, Japan, March 25-30, 2012.
- J. Riedy, H. Meyerhenke, and D.A. Bader, "Scalable Multi-threaded Community Detection in Social Networks," 6th Workshop on Multithreaded Architectures and Applications (MTAAP), Shanghai, China, May 25, 2012.
- H. Meyerhenke, E.J. Riedy, and D.A. Bader, "Parallel Community Detection in Streaming Graphs," Minisymposium on Parallel Analysis of Massive Social Networks, 15th SIAM Conference on Parallel Processing for Scientific Computing (PP12), Savannah, GA, February 15-17, 2012.
- D. Ediger, E.J. Riedy, H. Meyerhenke, and D.A. Bader, "Analyzing Massive Networks with GraphCT," Poster Session, 15th SIAM Conference on Parallel Processing for Scientific Computing (PP12), Savannah, GA, February 15-17, 2012.
- R.C. McColl, D. Ediger, and D.A. Bader, "Many-Core Memory Hierarchies and Parallel Graph Analysis," Poster Session, 15th SIAM Conference on Parallel Processing for Scientific Computing (PP12), Savannah, GA, February 15-17, 2012.
- Computing (PP12), Savannah, GA, February 15-17, 2012.
 E.J. Riedy, D. Ediger, H. Meyerhenke, and D.A. Bader, "STING: Software for Analysis of Spatio-Temporal Interaction Networks and Graphs," Poster Session, 15th SIAM Conference or
- Parallel Processing for Scientific Computing (PP12), Savannah, GA, February 15-17, 2012.
 Y. Chai, Z. Du, D.A. Bader, and X. Qin, "Efficient Data Migration to Conserve Energy in Streaming Media Storage Systems," IEEE Transactions on Parallel & Distributed Systems, 2012
- M. S. Swenson, J. Anderson, A. Ash, P. Gaurav, Z. Sükösd, D.A. Bader, S.C. Harvey and C.E Heitsch, "GTfold: Enabling parallel RNA secondary structure prediction on multi-core desktops." BMC Research Notes, 5:341, 2012.
- D. Ediger, K. Jiang, E.J. Riedy, and D.A. Bader, "GraphCT: Multithreaded Algorithms for Massive Graph Analysis," IEEE Transactions on Parallel & Distributed Systems, 2012.
- D.A. Bader and K. Madduri, "Computational Challenges in Emerging Combinatorial Scientific Computing Applications," in O. Schenk, editor, Combinatorial Scientific Computing, Chapman & Hall / CRC Press, Chapter 17, pages 471-494, 2012.
- O. Green, R. McColl, and D.A. Bader, "GPU Merge Path -- A GPU Merging Algorithm," 26th ACM International Conference on Supercomputing (ICS), San Servolo Island, Venice, Italy, June 25-29, 2012.
- O. Green, R. McColl, and D.A. Bader, "A Fast Algorithm for Streaming Betweenness Centrality," 4th ASE/IEEE International Conference on Social Computing (SocialCom), Amsterdam, The Netherlands, September 3-5, 2012.
- D. Ediger, R. McColl, J. Riedy, and D.A. Bader, "STINGER: High Performance Data Structure for Streaming Graphs," The IEEE High Performance Extreme Computing Conference (HPEC), Waltham, MA, September 20-22, 2012. Best Paper Award.
- J. Marandola, S. Louise, L. Cudennec, J.-T. Acquaviva and D.A. Bader, "Enhancing Cache Coherent Architecture with Access Patterns for Embedded Manycore Systems," 14th IEEE International Symposium on System-on-Chip (SoC), Tampere, Finland, October 11-12, 2012.
- L.M. Munguía, E. Ayguade, and D.A. Bader, "Task-based Parallel Breadth-First Search in Heterogeneous Environments," The 19th Annual IEEE International Conference on High Performance Computing (HiPC), Pune, India, December 18-21, 2012.

Bader, Related Recent Publications (2013)



- X. Liu, P. Pande, H. Meyerhenke, and D.A. Bader, "PASQUAL: Parallel Techniques for Next Generation Genome Sequence Assembly," IEEE
 Transactions on Parallel & Distributed Systems, 24(5):977-986, 2013.
- David A. Bader, Henning Meyerhenke, Peter Sanders, and Dorothea Wagner (eds.), Graph Partitioning and Graph Clustering, American Mathematical Society, 2013.
- E. Jason Riedy, Henning Meyerhenke, David Ediger and David A. Bader, "Parallel Community Detection for Massive Graphs," in David A. Bader, Henning Meyerhenke, Peter Sanders, and Dorothea Wagner (eds.), Graph Partitioning and Graph Clustering, American Mathematical Society, Chapter 14, pages 207-222, 2013.
- S. Kang, D.A. Bader, and R. Vuduc, "Energy-Efficient Scheduling for Best-Effort Interactive Services to Achieve High Response Quality," 27th IEEE International Parallel and Distributed Processing Symposium (IPDPS), Boston, MA, May 20-24, 2013.
- J. Riedy and D.A. Bader, "Multithreaded Community Monitoring for Massive Streaming Graph Data," 7th Workshop on Multithreaded Architectures and Applications (MTAAP), Boston, MA, May 24, 2013.
- D. Ediger and D.A. Bader, "Investigating Graph Algorithms in the BSP Model on the Cray XMT," 7th Workshop on Multithreaded Architectures and Applications (MTAAP), Boston, MA, May 24, 2013.
- O. Green and D.A. Bader, "Faster Betweenness Centrality Based on Data Structure Experimentation," International Conference on Computational Science (ICCS), Barcelona, Spain, June 5-7, 2013.
- Z. Yin, J. Tang, S. Schaeffer, and D.A. Bader, "Streaming Breakpoint Graph Analytics for Accelerating and Parallelizing the Computation of DCJ Median of Three Genomes," International Conference on Computational Science (ICCS), Barcelona, Spain, June 5-7, 2013.
- T. Senator, D.A. Bader, et al., "Detecting Insider Threats in a Real Corporate Database of Computer Usage Activities," 19th ACM SIGKDD Conference on Knowledge Discovery and Data Mining (KDD), Chicago, IL, August 11-14, 2013.
- J. Fairbanks, D. Ediger, R. McColl, D.A. Bader and E. Gilbert, "A Statistical Framework for Streaming Graph Analysis," *IEEE/ACM International Conference on Advances in Social Networks Analysis and Modeling* (ASONAM), Niagara Falls, Canada, August 25-28, 2013.
- A. Zakrzewska and D.A. Bader, "Measuring the Sensitivity of Graph Metrics to Missing Data," 10th International Conference on Parallel Processing and Applied Mathematics (PPAM), Warsaw, Poland, September 8-11, 2013.
- O. Green and D.A. Bader, "A Fast Algorithm for Streaming Betweenness Centrality," 5th ASE/IEEE International Conference on Social Computing (SocialCom), Washington, DC, September 8-14, 2013.
- R. McColl, O. Green, and D.A. Bader, "A New Parallel Algorithm for Connected Components in Dynamic Graphs," The 20th Annual IEEE International Conference on High Performance Computing (HiPC), Bangalore, India, December 18-21, 2013.

Bader, Related Recent Publications (2014-2015)



- R. McColl, D. Ediger, J. Poovey, D. Campbell, and D.A. Bader, "A Performance Evaluation of Open Source Graph Databases," The 1st Workshop on Parallel Programming for Analytics Applications (PPAA 2014) held in conjunction with the 19th ACM SIGPLAN Symposium on Principles and Practice of Parallel Programming (PPOPP 2014), Orlando, Florida, February 16, 2014.
- O. Green, L.M. Munguia, and D.A. Bader, "Load Balanced Clustering Coefficients," The 1st Workshop on Parallel Programming for Analytics Applications (PPAA 2014) held in conjunction with the 19th ACM SIGPLAN Symposium on Principles and Practice of Parallel Programming (PPOPP 2014), Orlando, Florida, February 16, 2014.
- A. McLaughlin and D.A. Bader, "Revisiting Edge and Node Parallelism for Dynamic GPU Graph Analytics," 8th Workshop on Multithreaded Architectures and Applications (MTAAP), held in conjuntion with The IEEE International Parallel and Distributed Processing Symposium (IPDPS 2014), Phoenix, AZ, May 23, 2014.
- Z. Yin, J. Tang, S. Schaeffer, D.A. Bader, "A Lin-Kernighan Heuristic for the DCJ Median Problem of Genomes with Unequal Contents," 20th International Computing and Combinatorics Conference (COCOON), Atlanta, GA, August 4-6, 2014.
- Y. You, D.A. Bader and M.M. Dehnavi, "Designing an Adaptive Cross-Architecture Combination for Graph Traversal," *The 43rd International Conference on Parallel Processing* (ICPP 2014), Minneapolis, MN, September 9-12, 2014.
- A. McLaughlin, J. Riedy, and D.A. Bader, "Optimizing Energy Consumption and Parallel Performance for Betweenness Centrality using GPUs," The 18th Annual IEEE High Performance Extreme Computing Conference (HPEC), Waltham, MA, September 9-11, 2014.
- A. McLaughlin and D.A. Bader, "Scalable and High Performance Betweenness Centrality on the GPU," The 26th IEEE and ACM Supercomputing Conference (SC14), New Orleans, LA, November 16-21, 2014. Best Student Paper Finalist.
- D. Dauwe, E. Jonardi, R. Friese, S. Pasricha, A.A. Maciejewski, D.A. Bader, and H.J. Siegel, "A Methodology for Co-Location Aware Application Performance Modeling in Multicore Computing," 17th Workshop on Advances on Parallel and Distributed Processing Symposium (APDCM), Hyderabad, India, May 25, 2015.
- A. Zakrzewska and D.A. Bader, "Fast Incremental Community Detection on Dynamic Graphs," 11th International Conference on Parallel Processing and Applied Mathematics (PPAM), Krakow, Poland, September 6-9, 2015.
- A. McLaughlin, J. Riedy, and D.A. Bader, "An Energy-Efficient Abstraction for Simultaneous Breadth-First Searches," The 19th Annual IEEE High Performance Extreme Computing Conference (HPEC), Waltham, MA, September 15-17, 2015.
- A. McLaughlin, D. Merrill, M. Garland and D.A. Bader, "Parallel Methods for Verifying the Consistency of Weakly-Ordered Architectures," The 24th International Conference on Parallel Architectures and Compilation Techniques (PACT), San Francisco, CA, October 18-21, 2015.

Acknowledgment of Support







































